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USING A FIRST ORDER MARKOV CHAIN MODEL AND SPI INDEX TO FORECASTING, MONITORING AND ZONING OF METEOROLOGICAL DROUGHT CASE STUDY: CHAHAR MAHAL AND BAKHTIARI PROVINCE, IRAN

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ABSTRACT

The objective of this research was to examine and forecast the intensity, duration, frequency and extent of droughts in Chahar Mahal and Bakhtiari province of Iran for the 120 next months using the first order Markov chain model and the time series of Standardized Precipitation Index (SPI) in the three-month time scale. For this, precipitation data within the same statistical period of 30 years (1983-2012) in 1 time scales of 3 months from 12 stations located within the province were used. The results were shown that in 3months time scale, about 70 percent of the condition was normal and about 15-20 percent of the drought conditions have been occurred. Also likely of remains in the drought trap for all stations is more than 40 percent and it will be more in the South and South- East regions of the province. According to the results, the probability of transition from dry to wet conditions in the central part of the province is more than elsewhere. And droughts in the south and south-east of the province were of higher intensity and longer duration than elsewhere. According to calculated balance probability matrix the value of balance probability of drought is more than wet years in the province.

Key Words : Drought, Meteorological, Markov chain model, SPI Index, Balance probability matrix

INTRODUCTION

Drought is a natural occurring phenomenon related to a significant decrease of water availability during a long period of time and over a large area. Drought has many effects on man's economic activities, human lives and various elements of the environment such as the Earth's ecosystems. The origin of drought is impossible to define much as the starting point of the global hydrological cycle. Conventionally, decrease of precipitation is considered as the origin of drought. This leads to a reduction of storage volumes and fluxes involved in the hydrological cycle depending on the choice of the hydrological or agricultural. Drought is an unexpected reduction in rain during a certain time in an area which is not necessarily arid. Characterizing periods of deficit and drought has been an important aspect of planning and management of water resources systems for many decades. So should be reducing problems raised by this phenomenon with producing a plan for its management. Drought is one of the most harmful natural disasters that affected the human population. Due to various factors are involved in drought phenomenon directly and indirectly, it is difficult to define it and therefore no comprehensive and acceptable definition is existed among all researchers as yet. Due to the random occurrence of drought, study of its behaviour requires the use of statistical

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methods and at first time was considered by Yevjevich and after that many scientists began to study the probabilistic properties of drought. Among natural disasters, the damage by drought is highest. Incidence of drought and floods have been prominent resulting in famines in many parts of mbabew perticulary in Masvingo province.[1] Parnali and Haque studied issues flood hazards management in canader.[2] Therefore, extensive monitoring and provide a warning system of drought in the prone areas of drought is inevitable. For identify and compare events should be quantified or measured them. Thus, to study drought and compare it in the different times drought monitoring is necessary.[3] One of the cognition problems is the lack of a precise and comprehensive definition of drought. Drought is classified to three meteorological, hydrological and agricultural categories. Meteorological drought is occur when rainfall is less than its average value during the given time period. Hydrological drought is caused surface of water flows and water levels in lake and water resources and groundwater table level will fall down. One of the essential tools for monitoring drought is use of drought index. Nowadays for quantitative statement of drought phenomenon and also evaluate it in the different temporal and spatial scales is used different indicators based on its types. Due to variable meteorological conditions affecting drought phenomenon from one point to another each index is valid only for the specific region. One of the most important indexes used in drought studies is the standardized precipitation index. That in this study it is used for zoning and forecasting drought in Chahar Mahal and Bakhtiari province. Mckee and et al. were applied SPI index at first in Colorado and found out Gamma distribution is the best distribution to fit the rainfall data. Standardized precipitation index was used for drawing monthly drought zoning maps in short-term, medium-term and long-term time scale in Italy.[3] Bronini and et al also showed that the standardized precipitation index can be very useful to quantify drought.[4] Ansafi moghadam and et al have been analyzed drought using Standardized Precipitation Index (SPI) in a study using data from 44 years of rainfall in 34

stations in the catchment of salt lake. In order to analyze the spatial intensity they were used the inverse distance method. Their results were shown stations that placed in center and east of basin have severe periods of drought.[5] Morid and et al were compared efficiency of seven drought index in Tehran province using 32 years data of the city and results of their study showed indices have a same performance in drought identify and indices of rainfall deciles have more sensitive to rainfall events in one year.[6] Moradi and et al were investigated and forecasted time, frequency and comprehensively of drought during 32 years (1968-1999) using data of 26 stations based on standard rainfall index in and out of Fars province. The results of the maps of drought duration in various periods showed that droughts in the south of the province were of higher intensity and longer duration than elsewhere.[7] Khalili and et al were investigated analysis of differences and similarities of two SPI and RDI drought indices. The results shown these two indices in all states have a similar manner; however RDI drought index shows drought in the more intensive state.[8] Edossa and et al. are discussed drought characteristics analysis based on meteorological and hydrological variables in the Avash river basin. In this study, they using the Standardized Precipitation Index concluded that in the 12-month time scale very severe drought was occurred in the upper and middle basin.[9] Kim and et al. have been investigated meteorological drought in 200 years (1807-2006) in Seoul, South Korea using two indices SPI and EDI. The results indicated that the EDI than SPI index was efficient estimation of the drought.[10] Al-Qinna and et al. investigated drought and its negative effects on social, economic, environmental and agriculture in Jordan. They have been used three indices SPI, DPI, and RAI to quantify. Their results have been shown that in the last 35 years drought was frequented with non-uniformity frequency. And its amount, duration and zoning have been changed from normal level to a very high intensive level, especially in the last decade.[11]

Drought and its features prediction are very important in the management of water resources. Self-correlation and Markov chain models are one of the time series models used to predict the probability of rainfall and drought. Markov chain model is used for random processes properties definition (such as hydrological and meteorological variables). Among the statistical methods, Markov chain model has been taken into consideration on climate science in recent years. Markov chain models are widely used in various sciences such as meteorology, economics and industry. Markov chain models are widely used in various sciences such as meteorology, economics and industry. Gabriel and Newman were used of a first order Markov chain model for determined wet and dry days using daily precipitation data in the area of occupied Palestine. Thomson was used of first-order Markov chain model and Palmer Index to determine transition probability matrix and zoning the likelihood drought, wet and normal conditions in the United States in Central America. Some of the other studies about using of Markov chain models and forecasting drought are listed in fallowing Chen-hua Chung and et al.[12] Antonino Cancelliere,[13] Monirsadat Tabatabaeezade and et al.[14-17] K.E. Logan, et al.[18] Raziei, T., I. Bordi, L. S. Pereira and A. Sutera.[19,20]

AIMS AND OBJECTIVES

To calculate time series of Standardized Precipitation Index (SPI) using Markov chain model. The potential of models to forecast drought over different lead times are discussed here.

MATERIAL AND METHODS

Study area

Chaharmahal and Bakhtiari province with an area of 16,532 square kilometers is located between 31 degrees and 9 minutes to 32 degrees and 48 minutes north latitude and 49 degrees and 28 minutes to 51 degrees and 25 minutes east longitude and it is limited from the North and East to Isfahan province, from the west to Khuzestan province in the south to Kohkilooyeh and Boyer Ahmad province and the North-west to Lorestan province. In this study, we have been used monthly rainfall data from 12 rain gaging, synoptic and Climatology stations that their details are given in **Table 1**. After doing homogeneity test of data, 30 years statistical period is considered from 1982-1983 to 2011-2012. Location of studied stations in Chahar Mahal and Bakhtiari province is shown in **Fig. 1**.

Data fit to statistical distribution

Some of researchers are used the standard number without data fitted on the statistical distribution incorrectly, instead of the Standardized Precipitation Index (SPI). While in this article at the first step after collecting statistics of the 30 years from the 12 mentioned stations in **Table 2** and run tests have been done to determine the homogeneity of the data and then the monthly rainfall values of each station for the time scale (3 months) are calculated. In 3 months' time scale summation of precipitation in April, May and June is considered as the rainfall index in June. Similarly, the summation of rainfall in May, June and July as the index of month of July, and continue as this method for other months. Thus, a time series of rainfall during the period for each station is obtained and in fact, the amount of rainfall in each month is obtained from summation of that month and two months before. Then Two-parameter gamma distribution was converted to the Z standard index with mean 0 and variance 1 using two linear -moment and momentum methods in software HYFA that in fact this random variable is the interest value of SPI. Also, fit test proper of statistics distribution is done with K-squares and maximum likelihood methods for the cumulative amount of rainfall per month and after calculate the Gamma cumulative probability in each time scale and for each month of the year, it may be converted to a normal random variable.

Table 1 : Name and coordinate of studied stations

Number	Stations name	Elevation (m)	UTM(X)	UTM(Y)
N1	Borujen	2245	526181	3536008
N2	Marghmalek	2470	45337	3593441
N3	Lordegan	1582	480798	3486943
N4	Beheshtabad	1686	464777	3543893
N5	Shahrekord	2058	4888274	3576020
N6	Farsan	2059	458445	3569353
N7	Averegan	2405	495284	3529840
N8	Naghan	1997	473705	3533287
N9	Chelgerd	2372	417598	3591622
N10	Gerdbisheh	2030	517964	3498049
N11	Monj	1416	465317	3488808
N12	Yancheshme	2238	462737	3605780

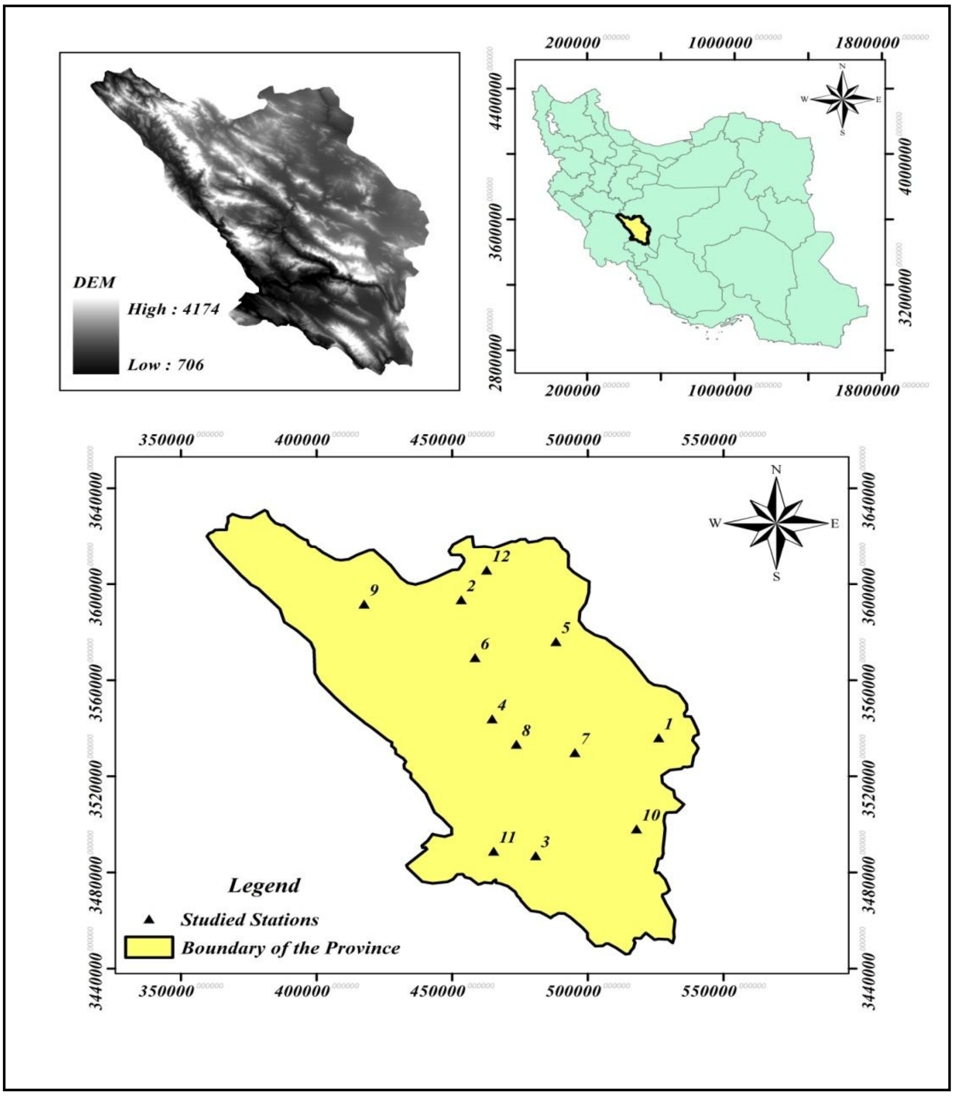

Fig. 1 : Location of studied station in the Chahar Mahal and Bakhtiari province

SPI Index

To calculate SPI index can be fit monthly rainfall and total precipitation in any desired period of time (three months, six months, etc.) using an appropriate distribution such as Gamma distribution or Pearson Type III. McKee was proposed Gamma distribution as the best fit of the monthly precipitation. Probability density function of the Gamma distribution for x> 0 is calculated according to the following formula.

$$\mathrm{G(x)} = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \mathrm{x}^{\mathrm{a}-1}\mathrm{e} - \mathrm{x}^{1-\beta} \quad (1)$$

In the above equation a>0 is the shape parameter, β<0 is the scale parameter of the Gamma distribution and x> 0 is the value of rainfall. In this equation Γ (α) is the Gamma function and defined as follows.

$$\Gamma(\alpha) = \lim_{n\to\infty} \prod_{v=0}^{n-1} \xrightarrow[\mathrm{y+v}]{\mathrm{n!n^{y-1}}} = \int_0^{\infty} \mathrm{y}^{\mathrm{a}-1}\mathrm{e}^{-\mathrm{y}}\mathrm{dy} \quad (2)$$

To fit the Gamma distribution to the rainfall data is needed a and β are calculated. To estimate these two parameters the maximum likelihood method is suggested that are defined as fallow.

$$\mathrm{a} = \frac{1}{4\mathrm{A}}\left(1 + \sqrt{1 + \frac{4\mathrm{A}}{3}}\right) \quad (3)$$

$$\beta = \frac{\overline{\mathrm{X}}}{\tilde{\mathrm{a}}} \quad (4)$$

In equation (3) A value for n observation is calculated as fallow.

$$A = \ln(\overline{\mathrm{X}}) - \frac{\sum \mathrm{In(x)}}{\mathrm{n}} \quad (5)$$

In the equation (5), n is the number of observations that precipitation is occurred in it and X^{-} is average rainfall in the desierd time period (monthly, quarterly, etc.). Using the above parameters can be calculated cumulative probability of precipitation at the desired scale for each station. Assuming t = x / B, cumulative probability will be in the form of the incomplete Gamma function and is defined as follows.

$$\mathrm{G(X)} = \int_0^{\mathrm{x}} \mathrm{g(x)dx} = \frac{1}{\Gamma(\alpha)}\int_0^{\mathrm{x}} \mathrm{t}^{\tilde{\mathrm{a}}-1}\ \mathrm{e}^{-1}\,\mathrm{dt} \quad (6)$$

Since the Gamma function is not defined for x = 0 and rainfall data always contain a large number of observation with zero rainfall, cumulative probability of precipitation is as follows.

$$\mathrm{H(X)} = \mathrm{q} + (1-\mathrm{q})\mathrm{G(X)} \quad (7)$$

In the above equation q is the probability of zero rainfall. Finally, H(x) is transmitted to a standard normal distribution with average 0 and standard deviations 1using the 8 and 9 equations and this result is known as the SPI value. For $0<H(x)\leq 0.5$ we have:

$$Z = SPI = -\left(\mathrm{t} - \frac{\mathrm{c_0+c_1t+c_2t^2}}{\mathrm{1+d_1t+d_2t^2+d_3t^3}}\right) \quad (8)$$

And for $0.5<H(x)<1$ we have:

$$\mathrm{Z = SPI} = +\left(\mathrm{t} - \frac{\mathrm{c_0+c_1t+c_2t^2}}{\mathrm{1+d_1t+d_2t^2+d_3t^3}}\right) \quad (9)$$

For $0<H(x)\leq 0.5$ and $0.5<H(x)<1$ component t is obtained of 10 and 11 equation, respectively.

$$t = \sqrt{\mathrm{In}\left(\frac{1}{(\mathrm{H(x)})^2}\right)} \quad (10)$$

$$\mathrm{t} = \sqrt{\mathrm{In}\left(\frac{1}{(1.0-\mathrm{H(x)})^2}\right)} \quad (11)$$

Components c_0,c_1,c_2, d_1, d_2, d_3 are also the constants that are defined as follows.

$C_0 = 2.515517$	$d_1 = 1.432788$
$C_1 = 0.802853$	$d_2 = 0.189269$
$C_2 = 0.010328$	$d_3 = 0.001308$

Markov chain model

Markov chain model is a mathematical approach to modeling probabilistic processes. By assuming that the first order model of Markov chain is fitted well to the drought events, the first order Markov chain model that have six state were selected. Each data in this matrix, indicates the transmission probability of a particular drought class to another class.

Drought forecasting

After calculating SPI index, using **Table 2** drought and wet conditions are specified for the desired station in every month of every year and for each time scale and then its relative frequency is obtained and finally, using the Markov chain drought has been forecasted. In this paper transition probability matrix method is used for modeling. The steady-state matrix for different stations is shown in **Table 3**.

Drought zoning

In this study because of the small relative frequency in different conditions of drought and wet, for draw zoning map the summation of relative frequency of drought conditions (moderate, severe and very severe) are considered as drought year and each of three wet states (moderate, severe and very severe) are considered as wet year. Also we were used distance inverse square method and Arc GIS 9.3 software for interpolation and mapping.

Table 2 : Drought categories based on the Standardized Precipitation Index (SPI)

SPI Value	Category
Extremely wet	2.0+
Very wet	1.5 to 1.99
Moderately wet	1.0 to 1.49
Near normal	-0.99 to 0.99
Moderately dry	-1 to -1.49
Severely dry	-1.5to -1.99
Extremely dry	-2 and less

RESULTS AND DISCUSSION

Transition probability matrix is calculated based on three dry, normal and wet conditions and the results are shown in **Table 3**. According to this transition probability matrix transition probability from one drought condition to another drought condition in all stations is above 40%. Most and lowest transition probabilities from a drought condition to another drought condition are belonging to Lordegan station and Chelgerd station, respectively. Also, based on this matrix transition probability from a certain condition to itself is high and the transition probability from drought condition in all stations is less and almost is less than other conditions. So we can say in the entire province, the probability that after a normal month comes a dry month is around 10 to 25 percent. Balance probability (stationary or stable) of each condition is calculated and presented in **Table 4**. Balance probability suggests that each station how many percentage of time can remains in the certain condition in the long-term. For example Chelgerd station has average balance probability of dry, normal and wet conditions about 24, 62 and 14%, respectively. Based on **Table 3** probability of staying in the normal condition is more than two other conditions in the region and possibility of drought condition is more than wet condition in the province. Expected numbers of events in each three dry, normal and wet conditions are shown in **Table 5**. Based on **Table 5** the number of normal condition is more than two other conditions and number of drought condition is more than wet condition in the most stations. Average predicted continuity of drought period in the quarter time scale is calculated and shown in **Table 6**. Lowest value of predicted continuity is in the Chelgerd station with continuity equal to 1.14 months and highest continuity is in the Lordegan station with the continuity equal to 2.64 months. These calculations can be used in water resources planning and drought combating, particularly. After above calculations, spatial distribution of remain probability in the drought trap ($P_{D,D}$) in southern and east southern parts is more than elsewhere of the province. This condition in the northern parts of the province is less than central parts. Also according to the earned results, transition probability from drought to wet condition that in the parts of central and northern of province is more than other regions of the province. Southern regions of the province have a worse condition for transition from drought to wet condition and drought continuity is between 1.71 to 2.14 months in most parts of the province. In the near of Chelgerd station and in northern parts of the province drought continuity is low and around 1.14 to 1.71 months. While in the Lordegan station and its surrounding drought continuity received to around 2.7 months. This probability have an increasing trend in crossing over from North to South of the province. And also this probability is less than other stations in two Avargan and Naghan stations as well as Chelgerd, Farsan, Yancheshmeh and marghmalek stations.

Table 3 : Transition probability matrix for studied stations

Station	Condition	N	W	D	Station	Condition	N	W	D
N1	N	0.66	0.18	0.17	N7	N	0.69	0.21	0.102
	W	0.46	0.43	0.11		W	0.51	0.39	0.103
	D	0.41	0.09	0.50		D	0.49	0.1	0.412
N2	N	0.76	0.18	0.07	N8	N	0.691	0.16	0.147
	W	0.44	0.37	0.2		W	0.509	0.42	0.076
	D	0.35	0.13	0.53		D	0.489	0.06	0.448
N3	N	0.68	0.15	0.18	N9	N	0.718	0.12	0.163
	W	0.33	0.40	0.27		W	0.411	0.41	0.176
	D	0.44	0.07	0.49		D	0.483	0.03	0.485
N4	N	0.71	0.10	0.18	N10	N	0.607	0.15	0.246
	W	0.31	0.47	0.22		W	0.405	0.41	0.189
	D	0.41	0.11	0.49		D	0.478	0.04	0.48
N5	N	0.66	0.17	0.18	N11	N	0.70	0.19	0.108
	W	0.40	0.41	0.19		W	0.438	0.55	0.017
	D	0.42	0.08	0.51		D	0.529	0.06	0.413
N6	N	0.69	0.16	0.16	N12	N	0.709	0.09	0.205
	W	0.31	0.39	0.31		W	0.428	0.46	0.114
	D	0.48	0.05	0.47		D	0.323	0.21	0.467

Table 4 : Balance probability of drought, normal and wet conditions for studied stations

Three months time series of SPI												
Station / Cond.	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12
Dry	0.23	0.175	0.279	0.271	0.266	0.192	0.148	0.191	0.243	0.309	0.119	0.254
Normal	0.21	0.619	0.555	0.562	0.545	0.593	0.618	0.618	0.618	0.535	0.608	0.558
Wet	0.56	0.205	0.166	0.165	0.188	0.220	0.233	0.192	0.139	0.154	0.271	0.187

Table 5 : Number of expected drought events for studied stations

Three months time series of SPI												
Station / Cond.	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12
Dry	14	10	17	17	16	18	11	13	15	20	11	17
Normal	23	18	22	20	23	17	23	23	21	31	22	20
Wet	15	16	12	11	24	13	18	14	10	12	15	13

Table 6 : Average of drought period continuity for studied stations

Three months time series of SPI												
Station / Cond.	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12
Dry	2.08	2.10	2.64	1.95	1.78	1.59	2.70	1.81	1.14	2.46	2.40	1.28
Normal	2.93	4.10	3.11	3.50	2.93	4.30	3.24	3.25	3.55	2.13	3.34	3.44
Wet	1.76	1.57	2.78	1.90	0.93	1.70	1.63	1.70	1.71	1.62	2.21	1.85

CONCLUSION

In this study, drought and balance probability of this phenomenon is predicted using Markov chain model in Chahar Mahal and Bakhtiari province. The province's water resources are one of the important water resources among all provinces of Iran. So further investigation of drought, which has a direct effect on water resources in this province and other parts of the country has many advantages and is most important cases in water resource planning and management.

Based on findings of this study it is specified that spatial distribution of drought and balance probability of drought in Southern and South-East regians of provinces are higher than other areas. Over the past 25 years in the studied stations, about 70 percent of conditions are normal conditions, and about 20-15 percent are drought conditions. Also probability of remains in drought trap for all stations is more than 40 percent and in the South and South-East parts of the province will be greater that this result is quite consistent with the climate of these regions and rainfall value of this part of the province. According to the earned results, balance probability of a drought period in most parts of the province, has an almost identical continuity and relatively long period that for the wet province such as Chahar Mahal and Bakhtiari contains important warnings and represents an extended drought in most parts of the country. All the above points are check out; efforts against losses caused by drought, proper use of water resources, improving water use patterns in agriculture, industry and drinking, use of new science and technology in forecasting drought, meteorological and agricultural. It is suggested that investigation of drought is done in the important watershed of the country and the results can be used for long-term planning and even short term in the water resources management. Also use of the other predicting models such as time series models, intelligent models such as artificial neural networks and etc. in forecasting and geostatistical methods in zoning severity of drought is recommended.

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